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A Surface Reconstruction Algorithm based on Octree and Optimized Local Smooth Degree

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Abstract

Surface reconstruction algorithm is a research issue in the field of computer graphic, and it has wide application prospects in the fields of 3D geographical information system, computer-aided design and manufacture, reverse engineer. The paper proposes a region-growing algorithm for surface reconstruction. Firstly, split the scattered point cloud to child node of specified threshold size using octree; secondly, reconstruct local surface based on Delaunay regulation in child node; then join the local surface and optimize them through local smooth degree optimization standard and adjust the entire surface normal; finally the surface reconstruction is completed. The experiment results show that the algorithm can solve the problem of non-uniform sampling points set and cope with boundary, and it is fit for open and closed surface reconstruction. The complexity of the algorithm is stable and the realization of the algorithm is easy.

Keywords:Surface Reconstruction; Octree; Optimized Local Smooth Degree; Delaunay Regulation

1. Introduction

Surface reconstruction from unorganized point cloud is a research issue in the field of computer graphic[1]. Surface reconstruction has widely applied in the fields of computer-aided design (CAD), computer-aided manufacture (CAM), 3D geo-graphical information system (3D GIS), reverse engineer,

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virtual simulation. The aim of surface reconstruction is to recover the geometry shape of the object from point cloud[2]. To achieve the purpose of surface reconstruction, now the common reconstruction algorithm can be divided into four categories: sculpture-based algorithm, region-growing algorithm, implicit function approaches, the combination of region-growing and sculpture-based.

2. The Proposition of Algorithm

In sculpture-based algorithms, the typical algorithms is Boissonnat's algorithms[3], other algorithms contains α-shape algorithm[4][5], crust algorithm and UmbrellaFilter algorithm.

In region-growing algorithms, the typical algorithm is BPA algorithm[6]. other algorithms contains Huang and Menq's algorithm[7] and Wang Qing's algorithm[8]. Lin[2] and Tan's[9] .

In implicit function approaches, the typical approach is Hoppe's algorithm in 1992. Yan[10] and Zhou[11] improved this algorithm .

In the combination of region-growing and sculpture-based, Kuo[12],Zhu[13] and Li[14] are all reconstructed suface through the combination of region-growing and sculpture-based.

This paper propose an algorithm called Octree-based Optimized Local Smooth Degree algorithm (OOLSD), which belong to region-growing algorithms. Firstly, split the point cloud to some small specified point sets by the way of octree construction; then bulid triangulation mesh locally through region-growing algorithm in small point sets; the next step is to merge these local triangulations recursively by means of improved local smooth degree optimization standard and optimize them. Finally, entire surface triangulation is reconstructed completely. The idea of this algorithm is divide-and-rule. Firstly construct triangulation mesh in small point sets, so the reconstruction efficiency will improved because the search region is small and is local. In the process of recursively merging, the "stitch" and optimization operation are done between boundary triangles, therefore, the number of the bourdary of triangulation mesh does not increase fastly with the number of point, so the complexity of algorithm is stable.

3. Terms and Conception Descriptions

3.1. Algorithm Assumptions and Terms

- Defination 1 k-Nearest of point: Let $X=\{X_1,X_2,\ldots,X_n\}$ is a sampling point set of surface S to be reconstructed, the k-nearest points to X_i is called k-nearest of X_i, denoted by $Nbhd(X_i)$.
- Defination 2 The order of edge: In manifold surface, any edge of delaunay triangle is shared by two triangles, so the order of edge is 2 and all the edges which order is 1 are boundary edge. The vertex set which is made up of the vertexes of boundary edge is called boundary points of triangular mesh.
- Defination 3 Bridge edge: The shortest edge connected the boundary points of two triangular meshs is bridge edge.
- Defination 4 Local smooth degree: Let $\theta(t,nt_i)$ is dihedral angel between t and nt_i , Local smooth degree is defined by[15]. In formula (1), $1\leqslant n\leqslant 3$ and t_i is the adjacent triangle of t.

$$LSD=\frac{1}{n}\sum_{i=1}^{n}\cos(\theta(t,nt_i)) \tag{1}$$

- Defination 5 Optimized local smooth degree: Deriving from the definition 4, when the triangle which contain boundary edges generates a new triangle and optimize them, the calculation range of optimal local smooth degree is a polygon area composed by two triangles which share a common boundary edge and their adjacent triangles. In formula (2), $1 \leqslant n \leqslant 3$, $1 \leqslant m \leqslant 3$, t_i is the adjacent triangle of t, t_j is the adjacent triangle of t' , and t is the adjacent triangle of t',t and t' share a common boundary edge.

$$LSD' = \frac{\sum_{i=1}^{n} \cos(\theta(t, nt_i)) + \sum_{j=1}^{m} \cos(\theta(t', mt_j)) - \cos(\theta(t, t'))}{n + m - 1} \tag{2}$$

3.2. The Description of OOLSD Algorithm

3.2.1. Octree Split Point Set

Linear octree can save storage space and it is also more convenient for some operations, but become complicated when querying a node, and the query efficiency is not enough high. Since the algorithm of this paper uses the less search function, so the linear octree is adopted.

The principle of constructing linear octree: a cube contains original point set is broken up into eight equal sub-cubes, if the number of points in every sub-cube is less than the specified threshold K, then stop to devide the sub-cube, or continue to devide.

3.2.2. The Construction of Triangular Mesh in Subnode

According to the literature[9], the definition of triangle closed to the surface and the property of local flatness show that the dihedral angle between adjacent triangles closed to the surface must be obtuse angle.

Considering the delaunay principle that the minimum angle is maximum, these rules are employed to ensure the only triangle through the relative deviation of the length of three edges in triangle and the relative deviation of all dihedral angle between the triangle to be extended and its adjacent triangles. The order of edge is 2 at the most and the dihedral angles of adjacent triangles are obtuse. Let L_1, L_2, L_3 is the length of three edges of the new triangle, and L is the average length of three edges. Then, the relative deviation of edges l' is:

$$l' = \frac{|L_1 - L| + |L_2 - L| + |L_3 - L|}{L} \tag{3}$$

In formula (3), L is the average edge length of triangle.

$$\alpha' = \frac{|\alpha_1 - \alpha| + |\alpha_2 - \alpha| + |\alpha_3 - \alpha|}{\alpha} \tag{4}$$

In formula (4), α is the average angle of triangle. In some situation, the number of triangles adjoined the triangles to be expanded may be 0,1,2. 0 represents triangles to be expanded is start triangle. when the number is 1 and 2, formula (4) must be modified.

the approach of Delaunay triangulation construction in child node is as follows:

(1) Find a starting point P and begin to construct triangulation.

(2) Find the point Q nearest to P in the child node.

(3) Let PQ is expanding edge, find the point which make l' minimum and create the initial triangle T_0 as the triangle to expand.

(4) When search the first triangle that adjacent to T_0, select the triangle which the dihedral angle is obtuse and minimize l'.

(5) Continue to expand the triangle, and the criteria of selecting a new point of the triangle is: First, check the order of the expanding edge whether it is less than 2. If it is, then it can be extended; Secondly, the dihedral angle between the expanding triangle and new triangle is an obtuse; Finally, select the point which minimize the sum of l' and α'. When we create a new triangle, use breadth-first search strategy.

3.2.3. Merge triangular mesh between the child nodes

The steps of mergering algorithm is as follow:

- (1) In two mesh to be merged M_1 and M_2, if M_2 only has one point, then find the bridge edge directly and create a new triangle from boundary points, so the bridge edge is expanding edge.
- (2) In two mesh to be merged M_1 and M_2, if M_2 only has one edge, then find the bridge edge and make the bridge edge as expanding edge to find the third point that creating a new triangle from boundary points.
- (3) If two mesh to be merged M_1 and M_2 are all triangulation mesh, firstly, find bridge edge and compute the value of n_1n_2. If the value is greater than 0, they can be merged, or change all normals of M_2 and then bridge edge become the start edge to search the third point from the boundary points of M_1 and M_2. In the process of mergence, the important step is to optimize the triangulation. Because the result of construstion may not be optimal, the triangles must be optimized.
- (4)The approach of optimizing is as follows: The bridge edge is the edge to be extend. According to the mergence algorithm, we search the third point from the boundary points of M_1 and M_2 to construct triangle T_{new}, and then find the $T_{new'}$ which adjoin to T_{new} and boundary edge is their common edge. The next step is to compute the LSD' of quadrilateral composed by T_{new} and $T_{new'}$, if the dihedral angle after changing the diagonal is obtuse and the result of LSD' after changing the diagonal is greater than before, then the triangles changed is the correct result, or else do not change. If the dihedral angle after changing the diagonal is acute angle, then do not change.
- (5)In the process of extending, to optimize the mesh gradually, to execute steps (3) and (4) circularly, and complete the mergence of the two mesh. By the same way, to gradually merge child nodes belonging to the same root, recursively, to complete the mergence of the entire mesh.
- (6) Find the point which Z value is maximum in the whole point set, and compute the dot product of the normal of this point and (0,0,1), if the result is less than 0, then all the normal of triangles need to be reversed.

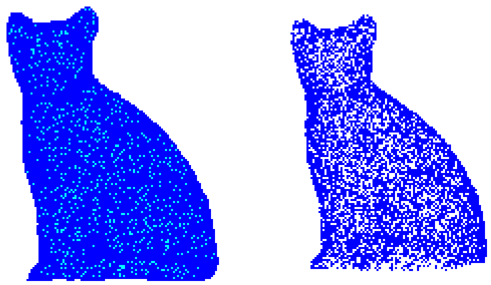
4. Experiment and Analysis

The algorithm of this paper is implemented based on VC++ 6.0 and Matlab. We use VC++ 6.0 to complete the main function of the algorithm, and use Matlab to display the result. Finally, the example is tested and verified.We use the cat model as the example to vertify the efficiency of the algorithm.The cat point set contains 10000 points and we set K is 8.the result contains 19883 triangles .the time consuming is 6.46s.

Figure 1 show that the algorithm can get a good reconstruction result, and consume less time. In the condition of satisfing assumption for the sample surface S, and the sampling rate within a reasonable range, the algorithm can reconstruct the correct results, and can handle opening and closing surface reconstruction.

5. Conclusion

The algorithm is based on recursive octree decomposition and mergence, relatively, so it is high in memory consumption. But the algorithm is based on local judgement and incremental approach, the speed of the recursive algorithm is faster, so the reconstruction algorithm has high efficiency. In the process of reconstruction, the algorithm only need to set the parameter of K, but the value of K should be in an appropriate range,typically,it is reasonable between 6 and 15, so the algorithm is highly automatic.



Any algorithm will not be common and has its particular application range.In paper's algorithm, The deficiency of the algorithm is that the complexity of the mergence opeation is the product of two boundary points number. If the algorithm of this part can be optimized, the speed of reconstruction will increase.

Fig. 1. (a) cat reconstruction result; (b) cat raw point set

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References

[1] RR, J. C., BEATSON,R. K.,CHERRIE, J.B.,MITCHELL,T.J., FRIGHT,W.R., MCCALLUM,B.C.,AND EVANS,T.R. Reconstruc-tion and representation of 3D objects with radial basis functions. In Proc.of ACM SIGGRAPH, 2001,67–76.
[2] Hong-Wei Lin, Chiew-Lan Tai, Guo-jin Wang. A Mesh Reconstruction Algorithm Driven by Intrinsic Property of Point Cloud [J]. Computer-Aided Design, 2004, 36(1):1-9
[3] Boissonnat J-D. Geometric structures of three-dimensional shape reconstruction.ACM Trans.Graphics,1984;3(4):266–86.
[4] Edelsbrunner H,Mucke E. 3D alpha shapes. ACM Transactions on Graphics, Vol.(13), No.(1),43–72
[5] Guo B, Menon J, Willette B. Surface reconstruction using alpha shapes. Comput Graphics Forum ,997;16(4):177-90.
[6] Bernardini F, Mittleman J, Rushmeier H,Silva C, Taubin G. The ballpivoting algorithm for surface reconstruction. IEEE Trans Visualization Comput Graphics 1999;5(4):349–59.
[7] Huang J,Menq CH.Combinatorial manifold mesh reconstruction and optimization from unorganized points with arbitrary topology. Comput-Aided Design,2002;(34):149–65.
[8] Qing Wang, Rong-qing Wang, Hujun Bao, et al. A fast progressive surface reconstruction algorithm for unorganized points[J].Journal of Software,2000,11(9):1221-1227.
[9] Jianrong Tan, Lixin Li. surface reconstruction algorithm based on properties of local smooth and the topology of scattered points [J].Journal of Software,2002, 13(11): 2121-2126.
[10] Jingqi Yan, Pengfei. Shi A new approach to 3D object surface reconstruction from unorganized points [J]. Chinese Journal of Computers,2001, 24(10):1051-1056.
[11] Rurong Zhou, Liyan Zhang, Xu Su, et al. massive the surface reconstruction algorithm of scattered points [J]. Journal of Software,2001,12 (2):249-255.
[12] Chuan-Chu Kuo,Hong-Tzong Yau. A Delaunay-based region-growing approach to surface reconstruction from unorganized point[J].Computer-Aided Design,2005,37:825-835.
[13] Qing Zhu, Fengchun Li, Yeting Zhang. An improved the region growing algorithm of three-dimensional point set [J].Wuhan University Journal,2006, 31(8): 667-670.
[14] Fengchun Li，Jun Gong，Qing Wang. Surface modeling approach based on the fine three-dimensional TIN [J]. Computer Applications，2006,8:159-161.
[15] Yongyu Zhang. Jinsong Ma . The algorithm of the linear octree to establish spatial index and query in 3D GIS[J]. Computer Engineering and Science,2009(2);61-63.